DESIGN OF A NEW LATTICE FOR POHANG LIGHT SOURCE

Eun-San Kim*
Pohang Accelerator Lab., POSTECH, Pohang, KyungBuk, 790-784 Korea

Abstract

A new lattice for low emittance at 2.5 GeV PLS stoarge ring was designed. We investigated the dynamic apertures in the lattice with the emittance of 10.3 nm to provide more brilliant synchrotron radiation. The dynamic apertures in the lattice without and with machine errors were examined by a tune survey to search for a large dynamic aperture. It was shown that how large were the dynamic apertures in the lattice compensated after corrections of a closed orbit distortions. The tune for the operation can be choosed on the view point of dynamic apertures obtained from a tune survey by a simulation method. It is also shown that the low emittance lattice may provide a sufficient dynamic aperture in the storage ring.

INTRODUCTION

In December 1994, Pohang Light Source (PLS) started to operate with 2 GeV electron beam. During January 2000 to October 2002, the operational beam energy in the ring was raised from 2 GeV to 2.5 GeV by energy ramping and PLS has been operating by 2.5 GeV full energy injection from the linac since October 2002. The present operating lattice in the 2.5 GeV ring has quite the same structure with that of the 2.0 GeV which has an emittance of 12.1 nm. The present lattice with emittance of 18.9 nm shows a larger emittance by around three times than another third generation synchrotron light sources in the world. Accordingly, design efforts for low emittance lattice for a high-brilliance at the PLS ring have been performed and it was shown that the beam emittance in the PLS ring can be reduced to 10 nm without any changing in the configuration of magnets. This can lead to a higher brilliance of the synchrotron radiation. We are also faced with the fact that the low emittance lattice may affect beam dynamics in the light source. It is necessary to estimate how a sufficient dynamic aperture for beam injection and storage into the ring can be obtained in the low emittance lattice. It is desirable to investigate scanning of the betatron tunes within a specified tune space to search for the optimal operation tune in the low emittance lattice. This point is a motivation of this paper. Accordingly, we investigated in detail the dynamic aperture for the lattice by a simulation method. The simulation was performed using the computer code Strategic Accelerator Design (SAD), which has been developed at KEK. The dynamic aperture in this simulation is defined as the maximum initial amplitude to give a circulation of 1000 turns. The simulation first shows the dynamic aperture for an ideal lattice without any errors. It then shows the dynamic aperture when some typical machine errors are included to the lattice. Errors due to the magnetic field, alignment, rotation, length, kick of steering magnet and beam position monitor are considered to be machine errors in the simulation. We then also investigated how large dynamic apertures due to corrections of the COD are recovered in the lattice. Accordingly, we could choose the operating tune in the lattice from the dynamic apertures obtained by a tune survey. In the next section, we give an overview on the machine of the PLS ring. Section 3 shows an explanation how to perform the tune survey in the paper. Section 4 gives a general illustration of the dynamic aperture. The dynamic apertures which result from a tune survey for the low emittance are shown in Section 4. The last section is devoted to conclusions.

* eskim1@postech.ac.kr

MACHINE OVERVIEW

Let us overvew the machine parameters for 2.5 GeV at PLS. The basic lattice structure of the PLS ring is TBA. Configuration of magnets for the low emittance lattice will not be changed and so it would not affect the existing beam lines of synchrotron radiation. Typical parameters in the present operating lattice and designed the low emittance lattice are given in Table I. Here, H and V mean the horizontal and vertical directions, respectively. The strengths ($1/m^2$) of the focusing and defocusing sextupole magnets to correct the chromaticities are also given.

DYNAMIC APERTURE

The dynamic aperture gives a description of the nonlinear effects arising from sextupoles to correct for the chromaticity and field imperfections of the magnets. In this stage of the design, it is necessary to estimate how large is the dynamic aperture of such a machine and how large is the dynamic aperture recovered by a correction of the COD. It is analytically difficult to obtain the dynamic aperture in the presence of nonlinear fields and thus in general it is obtained by a simulation method. The dynamic aperture is determined in a simulation as follows: first, set the initial amplitude of the betatron oscillation and track its amplitude through the ring's components. If the initial amplitude performs stable betatron oscillation within a region until given turns, we assume that a particle with its amplitude can infinitely perform stable betatron oscillation. Whether the initial amplitude can perform stable betatron oscillation until the given turns or not, we call this boundary value of its initial amplitude to the dynamic aperture. In electron storage rings, because an initial large amplitude dampens its amplitude by synchrotron radiation, we assume that 1000 turns is sufficient as a condition of stable betatron oscillation. Accordingly, we will investigate the dynamic aperture by tracking 1000 turns in our simulation. Next, we discuss how we evaluate the dynamic apertures which are obtained by a simulation method. The dynamic apertues are estimated in the position of straight section that insertion devices are located.

TUNE SURVEY

The dynamic aperture has a relation with the betatron tune. It is difficult to obtain analytically betatron tunes which enable us to provide a large dynamic aperture. To obatin a batatron tune which gives a large dynamic aperture, the only method is to check the dynamic aperture by changing the betatron tunes. Therefore, by changing the betatron tunes it is possible to obtain a resonable operating point which gives a large dynamic aperture.

We perform tune survey for the optics. The following method is applied for this tune survey: 1) The fractional tune is changed from the starting point. 2) The variation in the tune is done by 0.03 in a step and matching of the optics is performed. The tune survey is performed over the range between 0.0 and 1.0 in the horizontal and vertical directions, respectively. Accordingly, the tune survey covers a rectangular region in tune space ($0 \leq \nu_x \leq 1.0$ and $0 \leq \nu_y \leq 1.0$). 3) The dynamic aperture is obtained by averaging five points in the $X - Y$ plane, as shown in Fig. 1.

OPTICS AND DYNAMIC APERTURE FOR A LOW EMITTANCE LATTICE

Fig. 2 shows the optics for a low emittance of 10.3 nm at 2.5 GeV and its optical functions. Fig. 3 shows the dynamic aperture in the case that machine errors are not included. The magnitude of the dynamic aperture is expressed in unit of beam size, and is shown as the average value of five points in the $X-Y$ plane, as shown in Fig. 1. The particle momentum is kept at $\delta P/P$=0 during tracking. It is shown that the dynamic apertures are a little affected to resonances of $2n\nu_x = 12 \times 3n$ and $n\nu_y = 12 \times n$. Here n is integer. Next, we considered the effects of the machine errors on the dynamic aperture. The magnitudes of the errors considered in the simulation are listed in Table II. The errors are assumed to have a Gaussain distribution with the rms values given in Table II, and have been truncated by 3σ in their distributions. It is also important to show how large dynamic apertures in a ring with machine errors are recovered by a correction of the COD. Fig. 4 shows the dynamic apertures at the tune of $\nu_x = 17.64$ and $\nu_y = 11.6$ at the center of a straight section. Fig. 4(a) shows the dynamic apertures without machine errors. The dynamic apertures are shown in the cases of -1%, 0% and 1% momenta deviations. Fig. 4(b) shows the dynamic apertures with machine errors and corrections of COD in Fig. 4(a). It shows that vertical dynamic aperture is larger than the physical aperture in the vertical direction. The COD in Fig. 4(b) is 1.5 mm rms and 3.64 mm rms in the horizontal and vertical directions, respectively, before corrections of COD. The COD in Fig. 4(b) is adjusted to 0.12 mm rms and 0.97 mm rms in the horizontal and vertical directions, respectively, after corrections of COD. It is shown that correction of the COD is better performed in the horizontal direction than in the vertical direction. From these results, we expect that the PLS ring has a sufficient dynamic aperture in the low emittance lattice after a correction of the COD, if the machine errors are kept within the level given in Table II.

Table 1: Main parameters in the 2.5 GeV PLS storage ring

Parameters	**Present lattice**	**New lattice**
Lattice type	TBA	TBA
Circumference	280.56 m	280.56 m
Natural emittance	18.9 nm	10.3 nm
Momentum compaction	0.00181	0.00130
Energy spread	0.00085	0.00083
Synchrotron frequency	9.6 kHz	9.6 kHz
Betatron tune	14.28/8.18	17.64/11.6
Damping time(x/y/z)	8.5/8.5/4.3 ms	8.5/9.2/4 ms
Bunch length	7.6 mm	6.36 mm
Beam size(H) at ID	434 μm	223 μm
Beam size(V) at ID	27 μm	20 μm
Strength of sextupole	-6.4/4.4	-6.0/3.9
Energy aperture	1.5%	1.5%

Table 2: Machine errors in a lattice

Parameters	**Quad./Bending**	**Sextupole**
Magnetic field error(rms)	0.02 %	0.04 %
Alignment error(rms)	80 μm	80 μm
Rotation error(rms)	0.1 mrad	0.1 mrad
Length error(rms)	100 μm	100 μm

CONCLUSION

We investigated dynamic apertures in the designed low emittance lattice at the 2.5 GeV PLS storage ring. If the dynamic aperture is smaller than the physical aperture, it is actually difficult to inject a beam into a ring, which results in a bad beam lifetime. It is necessary to estimate the dynamic aperture of the machine for the sucessful operation of a ring. Thus, it requires estiamte of the effects on the dynamic aperture. Accordingly, we investigated in detail the dynamic aperture for the low emittance optics in the PLS ring. The dynamic apertures are obtained by scanning the betatron tunes within a specified tune space. The results of this simulation give an estimation for the requirement that the lattice provides a sufficient dynamic aperture in the PLS ring. When we estimate the dynamic aperture by the tracking method, the dynamic aperture in the low emittance lattice with a correction of the COD is considered to be sufficiently large for storage. Future work will include studies of tolerance of COD to keep enough dynamic aperture and how to reach such a level of COD. Tune which show comparative large dynamic aperture in tune space is considered. The tune may be adopted as operating tune in the stage of commissioning for the low emittance ring.

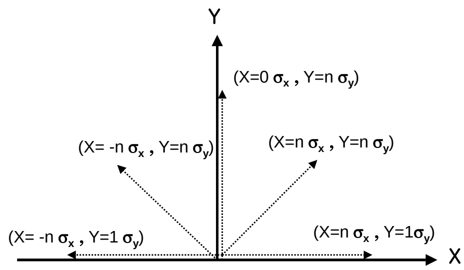

Figure 1: Survey of the dynamic aperture in the $X - Y$ plane. The dynamic aperture is obtained by averaging these five points.

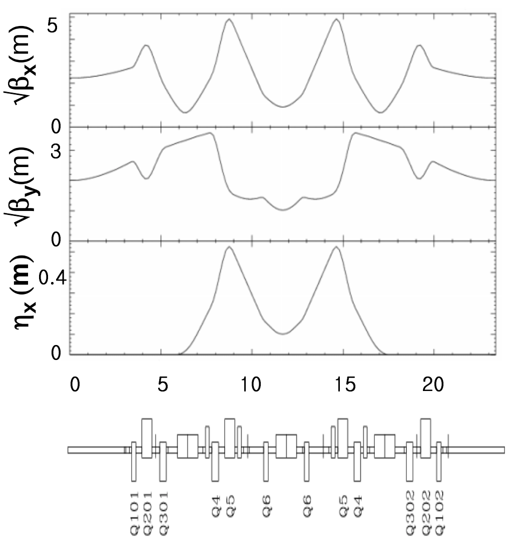

Figure 2: A low emittance lattice with emittance of 10.3 nm at 2.5 GeV.

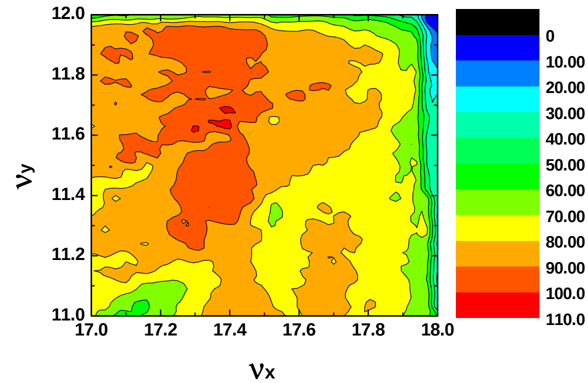

Figure 3: Dynamic apertures for tune survey in a low emittance lattice without machine errors. Most tunes show larger dynamic apertures than 70.

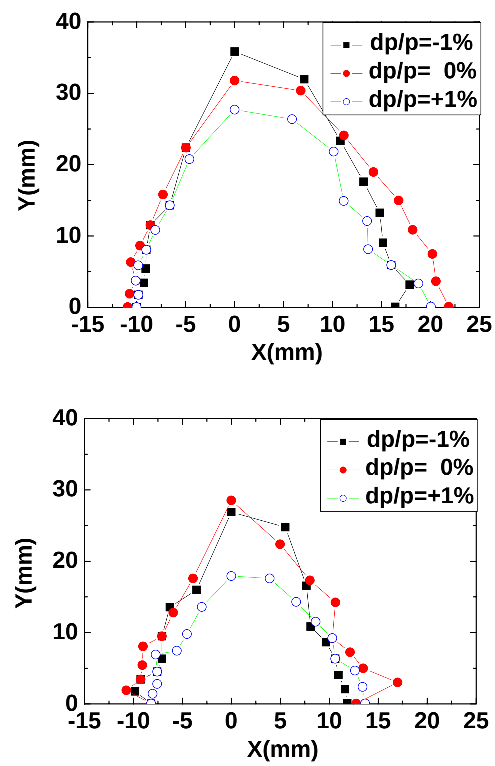

Figure 4: Dynamic apertures in the tune of $\nu_x = 17.64$ and $\nu_y = 11.6$ at the position of straight section. (a) without machine errors and (b) with machine errors and after corrections of the COD in (a).

REFERENCES

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